

NIMBUS 3 "SIRS" PRESSURE HEIGHT PROFILES AS COMPARED TO RADIOSONDES

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ABSTRACT

Tropospheric height and thickness values derived from Nimbus 3 Satellite Infra-Red Spectrometer (SIRS) sounding data are compared with nearby radiosonde data to determine (a) the accuracy and compatibility of SIRS data relative to the radiosonde and (b) the utility of SIRS data relative to the radiosonde, for objective analysis. The study shows that both the relative accuracy and the utility of the SIRS data are strongly dependent on cloud conditions, pressure level, and instrument status. SIRS thickness values in the upper troposphere compare well with radiosonde data. Loss of the 714 cm^{-1} channel in November 1969 greatly reduced the quality of the SIRS data, especially at lower levels; but prior to the loss, clear-air soundings show approximate parity with radiosonde observations.

1. INTRODUCTION

From the end of May 1969 through June 1970, height and temperature profiles were obtained on a real-time basis from Nimbus 3 SIRS observations and were included in analyses prepared by the National Meteorological Center (NMC). A complete description of the statistical techniques used to derive height and temperature data from the measured radiances is contained in Smith et al. (1970).

Of primary interest beyond obtaining usable data from SIRS soundings is the question of how well those data compare with conventional observations. Smith et al. (1970) compared the SIRS-derived temperatures and geopotential heights with those obtained from objective analysis of radiosonde data. They provided information on how SIRS and radiosonde values compare in root-mean-square (rms) error according to the age of the satellite and cloud conditions. However, from their comparisons it is not possible to estimate the accuracy of SIRS data as compared to that of the actual radiosonde data before the latter have been filtered in the objective analysis procedure.

This study compares constant-pressure height data (up to 100 mb) with height data obtained from conventional radiosonde observations. A technique for comparison is developed which permits an evaluation of the accuracy of SIRS data relative to the accuracy of radiosonde data. In addition, an estimate is made of the utility of SIRS data relative to radiosonde data in the operational objective analysis practiced at NMC.

The data investigated consist of five samples for the fall, winter, and spring of 1969–1970. These include early September, early October, late November and early December, mid-January, and early May. These samples were chosen not only to detail variations associated with seasonal change but also to ascertain the effects of changes in instrument status and modifications in the retrieval technique. Geographically, all samples are taken from Europe, the Atlantic, and North America, principally because of the requirement for reasonable time correspondence between SIRS and radiosonde data.

It is well known theoretically and empirically that cloud contamination greatly reduces the accuracy of data derived from measured radiances. For this reason, comparisons between SIRS and radiosonde data have been subdivided into three categories according to cloud condition estimates that were derived from the SIRS soundings themselves. These categories are designated *clear* for estimates of no cloud cover, *high* for estimates of 50 percent or more cloud cover at 500 mb or at least 10 percent above 500 mb, and *low* under any other conditions.

2. RELATIVE ACCURACY OF SIRS AND RADIOSONDE DATA

The technique for comparing the relative accuracy of SIRS and radiosonde data is based on situations where a SIRS sounding occurs in close proximity to a number of reporting radiosonde stations. Three categories of statistics were calculated to facilitate the comparison. The first of

these (designated as SIRS) involves the differences between the SIRS value and an average of the surrounding radiosonde values. The second category (designated as RAOB) involves the difference between the radiosonde value closest to the SIRS observation and an average of the remaining surrounding radiosonde values. In effect, in this second category a radiosonde is treated as a pseudo-SIRS. The third category (designated as ANALYSIS) involves the variance within the averaged radiosonde data used in the first two categories. Neither SIRS nor RAOB gives a measure of the absolute accuracy of the respective sounding technique because of the error contained in the averaged radiosonde data which serves as a basis for comparison. A gross estimate of the absolute accuracy is given by a comparison of either SIRS or RAOB with ANALYSIS. More importantly, however, a direct comparison of the SIRS and RAOB categories gives an estimate of the *relative* accuracy of SIRS as compared to radiosonde.

Details of the manner in which the three categories of statistics were obtained and their interpretation are contained in the appendix. In the following subsections, mean and rms discrepancies between SIRS and RAOB and averaged radiosonde neighbors are presented for thickness data between the mandatory pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100 mb); rms discrepancies are presented for height values at the mandatory pressure levels; and the rms variance of the radiosonde neighbors is presented at the mandatory pressure levels. These statistics are discussed chronologically for the five samples.

AUG. 31-SEPT. 10, 1969

Figure 1 depicts the rms and mean thickness discrepancies (top) and the rms height discrepancies (bottom) for both SIRS and RAOB for three cloud categories. Also shown is the standard deviation of radiosonde height values that are used in the averages (ANALYSIS). From the thickness data, it is apparent that SIRS is comparable to the radiosonde in the upper troposphere, except possibly for the high-cloud category. In the lower troposphere, the radiosonde shows clear superiority in the high-cloud cases and slight superiority in the low-cloud and clear cases. The greater variance of SIRS in the lower troposphere is to a large extent due to a bias toward high temperatures in the clear and high-cloud categories.

The height discrepancies shown in figure 1 indicate that the accuracy of SIRS height data at constant-pressure surfaces is quite similar to radiosonde accuracy throughout the troposphere in clear and low-cloud situations. Due to the large high-temperature bias, the SIRS heights under high-cloud conditions are poor for this sample. It should be noted that the correspondence at 850 mb is artificial because at this time and through the October sample, analyzed 850-mb heights were being used as a boundary condition for SIRS height retrievals.

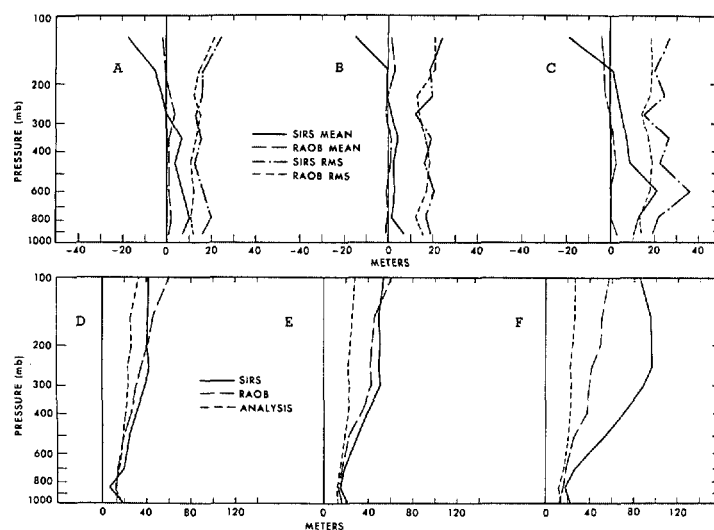


FIGURE 1.—Aug. 31-Sept. 10, 1969. Top: mean and rms discrepancies (m) discriminated according to cloud cover, between thickness values obtained from SIRS and from RAOB respectively compared with neighboring radiosondes. (A) cloud-free cases, (B) low-cloud cases, (C) high-cloud cases. Bottom: rms discrepancies between height values (m) obtained from SIRS and RAOB respectively compared with neighboring radiosondes. The standard deviation of the radiosonde height values (ANALYSIS) used for comparison with SIRS and RAOB is also shown. (D) cloud-free cases, (E) low-cloud cases, (F) high-cloud cases.

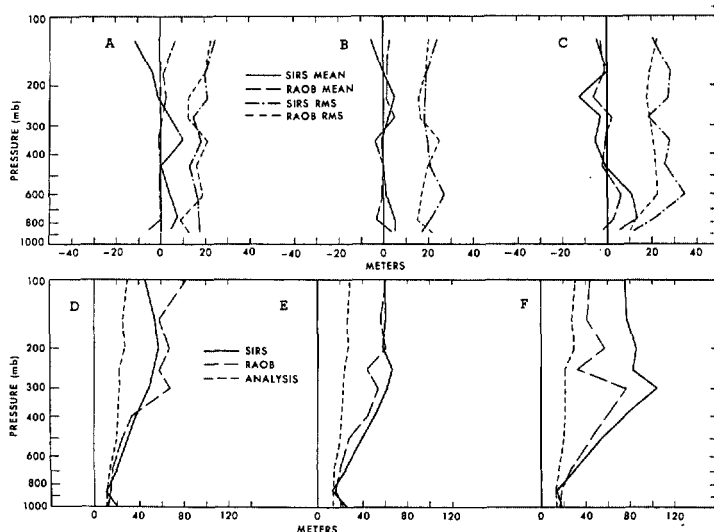


FIGURE 2.—Same as figure 1, for Oct. 2-10, 1969.

OCT. 2-10, 1969

This sample is the last taken prior to the exclusion of one radiance (714 cm^{-1}) from the retrieval technique and the removal of most high-cloud retrievals from the operational data. The relative accuracy of SIRS as compared to radiosonde data in this sample (fig. 2) is very similar to its relative accuracy in the September sample. In the lower troposphere, the SIRS data again show the high-temperature bias with a consequent slight inferiority to

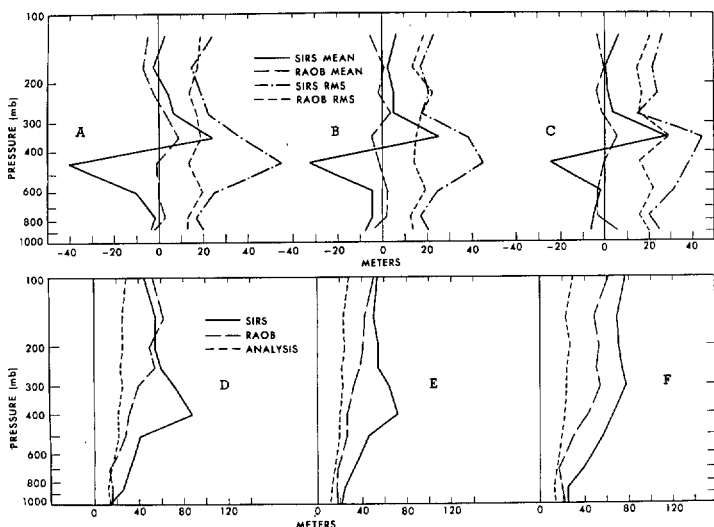


FIGURE 3.—Same as figure 1, for Nov. 23–Dec. 3, 1969.

the radiosonde data in clear and low-cloud situations and a substantial inferiority in high-cloud situations. The magnitudes of the discrepancies measured from the mean extrapolated radiosonde data are somewhat larger for all categories of both SIRS and RAOB. It is tempting to ascribe this effect to the greater variance of the atmosphere with the later season. However, such a conclusion is not supported by the later samples. The increase appears to be a sample characteristic rather than of seasonal origin.

NOV. 23–DEC. 3, 1969

This sample differs from earlier samples in that: 1000 mb has replaced 850 mb as a boundary condition, many of the retrievals in the high-cloud category have been eliminated, and one of the measured radiances is no longer used in the retrievals. The most obvious feature of the statistics (fig. 3) is that a problem exists with the 400-mb SIRS retrievals. SIRS heights at this level are much too low in the mean, irrespective of cloud category.

Disregarding 400 mb, at the lowest and highest levels the accuracy of SIRS as compared to radiosonde-measured thickness is not greatly different from earlier samples. The only significant change is that a low-temperature bias is now observed in the lower troposphere. The accuracy of SIRS height data at the highest levels remains comparable to the radiosonde in the clear and low-cloud categories. SIRS height data at lower levels have been degraded, but at least part of the degradation is due to the change in boundary condition.

To investigate the bias at 400 mb, we constructed semimonthly plots of vertical profiles of the regression coefficients used to compute SIRS height values for August 1969 through January 1970 (not shown). For the months of November and December, these profiles showed sharp discontinuities at 400 mb; whereas in other months

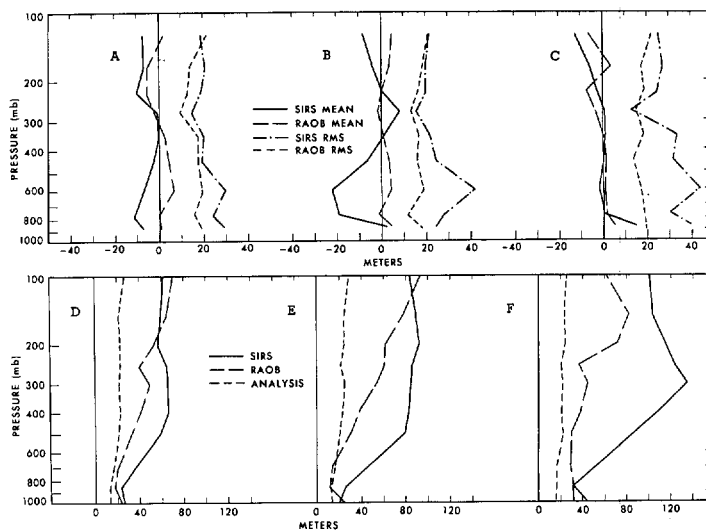


FIGURE 4.—Same as figure 1, for Jan. 8–21, 1970.

(earlier and later) the profiles varied smoothly with altitude. Since the regression coefficients were generated from NMC objective analyses of the height fields, it appears that the objective analyses at 400 mb were incorrect during November and December. However, it has not proved possible to ascertain the exact source of the problem.

JAN. 8–21, 1970

In the interim between the November and January samples, the retrieval technique was altered such that all heights above 700 mb were computed hydrostatically from the temperature retrievals. This modification was made chiefly because of the difficulties with November height retrievals at 400 mb. As a result, the discrepancy statistics shown for the January sample in figure 4 reflect the accuracy of temperature rather than height retrievals above 700 mb.

The statistics shown in figure 4 demonstrate a general deterioration of the SIRS data. The low-temperature bias in the lower troposphere is now pronounced in the clear and low-cloud categories. At high levels, the discrepancy between the SIRS and RAOB is more distinct in the thickness comparisons although the disparity is still not pronounced.

MAY 3–13, 1970

In March 1970, all SIRS data in the high-cloud category were eliminated from the operational data. Figure 5 presents statistics on relative accuracy for the clear and low-cloud categories in May.

The most noticeable change since January is that the disparity between SIRS and RAOB has considerably increased at the highest levels. The cause of this unexpected change is unknown. The low-temperature bias at low

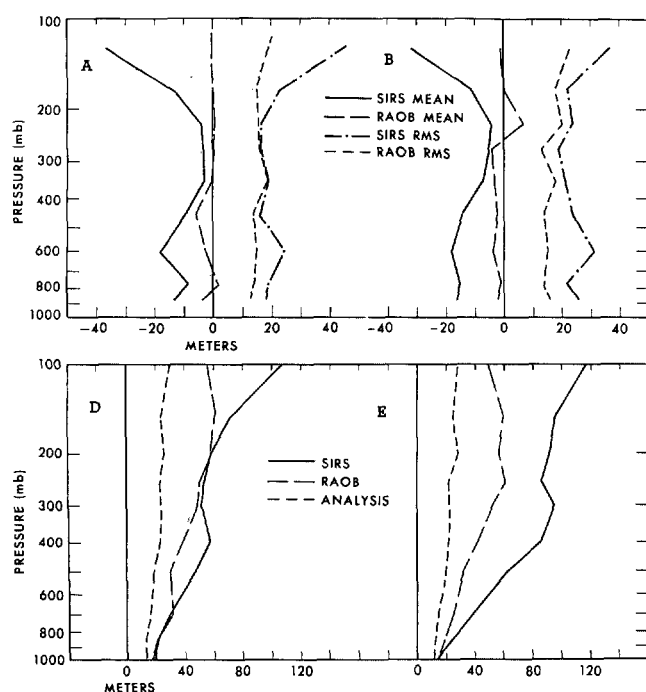


FIGURE 5.—Same as figure 1, for May 3–13, 1970, no high-cloud cases.

levels remains pronounced. The deterioration of the instrument is dramatically indicated by comparison of the October 1969 and May 1970 statistics (figs. 2 and 5). From a seasonal standpoint, the state of the atmosphere should be fairly similar. However, the SIRS data for May are far less accurate in the low-cloud category and at lower levels in the clear category.

3. RELATIVE UTILITY OF SIRS AND RADIOSONDE

The utility of an observation is here defined as its capacity to improve an operational objective analysis. The objective analysis method at NMC is a procedure wherein a slightly modified 12-hr forecast, valid at analysis time, is used as a first guess and adjusted according to real data. The question of the utility of SIRS data is considered from the aspect of their improving the coincident values in the forecast.

The averaged radiosonde neighbors around each SIRS and pseudo-SIRS are again used as the standard for comparison. If the absolute difference between an observation and the averaged radiosonde data is less than the absolute difference between the coincident value in the forecast height-field and the averaged radiosonde data, the observation is said to be more accurate than the forecast height-field and therefore useful to the analysis. In the following, utility is presented as the percentage of SIRS and RAOB data which is useful to the analysis.

The samples used to determine utility are larger than those used to determine relative accuracy. Only one instead of three radiosonde neighbors was required for inclusion in the statistics. This afforded a greater geo-

TABLE 1.—Utilities of SIRS (S) and RAOB (R) in percent. The relative usefulness of SIRS as compared to radiosonde data is indicated by comparing S with R.

Month	Cloud	Heights								Thickness	
		700 mb		500 mb		300 mb		200 mb		500–700 mb	
		S	R	S	R	S	R	S	R	S	R
September	clear	64	67	57	62	51	64	50	51	45	53
	low	57	59	50	57	49	57	41	48	43	54
	high	51	63	36	53	35	62	24	52	30	47
October	clear	60	65	49	58	44	50	44	56	42	43
	low	49	58	42	63	40	57	39	48	38	59
	high	38	60	28	49	35	56	32	52	29	42
November	clear	42	61	45	56	41	62	46	54	47	64
	low	46	61	40	58	44	69	39	53	38	61
	high	37	63	25	59	28	57	22	52	32	58
December	clear	46	69	42	67	40	64	41	66	42	58
	low	46	80	31	69	29	51	29	61	29	46
	high	34	73	28	68	22	63	20	57	24	57
January	clear	44	57	39	63	41	59	42	37	36	48
	low	34	55	32	50	41	47	32	43	27	50
	high										

graphical distribution and larger samples at the expense of accuracy in the mean radiosonde value used for comparison.

Even more so than in the previous discussion of accuracy, the magnitudes of the statistics must be viewed with caution. A utility of 50 percent does not necessarily mean that SIRS and forecast data are equally useful. There is again the problem of inaccuracies in the averaged radiosonde data, but in addition, the statistics are for the most part computed in dense data areas where the forecasts are most likely to be of high quality. Utilities in poor data areas, if they could be computed, would probably be higher. Nevertheless, a comparison between the utility obtained with SIRS data and that obtained with RAOB data is a reasonable test of the utility of SIRS as compared to radiosonde data.

Table 1 shows the utilities obtained with SIRS and RAOB data for the sample periods used in this study. For practical reasons, heights at only four pressure levels and thicknesses for only one layer were considered. Several of the features observed in the investigation of relative accuracy are evident in the utility statistics. The debilitating effect of cloud contamination appears in all samples. SIRS data are of lowest quality in January. The loss of the 714 cm^{-1} channel significantly degrades the SIRS data in the low-cloud category and at low levels in the clear category (cf. the 500-mb and 500–700-mb utilities for October and May).

The utility statistics show, in general, a greater disparity between SIRS and RAOB than do the relative accuracy statistics. In the latter, there are a number of instances, at least in the earlier samples, where SIRS data appear to equal or exceed the quality of radiosonde data. In the utility statistics, there are only a few instances where the SIRS data appear to equal the quality of the radiosonde data and these are all in the clear category (with the exception of the low-cloud utility at 700 mb in the September sample when 850 mb was being used as a reference level). In only one instance does the SIRS utility exceed that of the radio-

sonde, at 200 mb in May, and in this case the utility of the radiosonde is unusually low.

The greater disparity between SIRS and radiosonde soundings shown by the utility statistics is not readily explainable. It almost certainly is not caused by the different sample base. Relative accuracy statistics not presented here were computed for the larger samples requiring only one radiosonde neighbor and showed even closer correspondence between SIRS and RAOB than did the smaller samples. It is possible that the statistics are biased in favor of the radiosonde since the forecasts are closely dependent on the radiosonde data of 12 hr earlier and the 12-hr autocorrelation of radiosonde data is so high. However, a compensating bias in favor of SIRS almost certainly exists because RAOB comparisons cannot be made where only one radiosonde occurs. In such sparse data areas the forecast is likely to be poorer, with the result that computed utility will be higher than in good data areas. One is therefore left with the conclusion that, even when the relative accuracy of SIRS data appears to be close to that of the radiosonde, the small difference is probably significant in terms of the utility of the data.

4. DISCUSSION

From the aspect of accepting SIRS data with confidence equal to that given radiosonde data, the most important finding of this study is that SIRS thickness values at high levels display approximately the same accuracy as radiosonde measurements. The May 1970 sample was an exception, but the majority of evidence suggests that SIRS thickness data in the high troposphere can be accepted with the same confidence given to radiosonde values.

Conclusions regarding the lower troposphere are not so readily reached. The loss of the 714 cm^{-1} radiance measurements was critical for both the accuracy and utility of SIRS data in the troposphere, especially in the definition of heights at constant-pressure surfaces. The loss of this second-most transparent channel greatly reduced definition at low levels and certainly increased the error of the SIRS retrievals there. As noted earlier, during December the retrieval procedure was changed such that heights above 700 mb were computed hydrostatically from the temperature retrievals. Therefore, the increased error at low levels was forwarded to the higher levels as well. The loss of the 714 cm^{-1} channel also required reformulating the method of correcting for inferred cloud. A two-level model was replaced by a simpler one-level model. To what extent this change affected the retrievals is uncertain. It, together with the loss of the 714 cm^{-1} channel, was quite probably responsible for the sudden change from a high-temperature to a low-temperature bias in the lower troposphere.

There can be no doubt that, following the failure of the 714 cm^{-1} channel, SIRS data were significantly inferior to radiosonde data at least up through the middle troposphere. This conclusion is generally apparent in the relative accuracy statistics and very clear in the utility

statistics. Whether this result would have been obtained had the instrument behaved properly must remain a moot question. The relative accuracy statistics of the prefailure samples of September and October suggest close correspondence between SIRS and radiosonde, exclusive of situations where high cloud was sensed. However, the utility statistics of these samples suggest a definite disparity in cloudy situations and a slight disparity in clear situations. At best, it can be claimed that the quality of SIRS data approximated the quality of radiosonde data before the failure of the 714 cm^{-1} channel and when no cloud was sensed by the instrument.

Two areas most in need of improvement in SIRS retrievals are the treatment of the cloud problem and the specification of a tie-on level for establishing heights at constant-pressure levels. Some progress can and is being made on recognizing situations where cloudiness exists, but little more can be done to correct for cloudiness except to increase the resolution of future instruments. Work is in progress to improve the tie-on method, principally to improve height data at high levels when the low-level thicknesses are uncertain because of cloud contamination. It should be noted that this is, in a sense, an artificial problem created by the rather rigid dependence of current analysis and forecast procedures on height data at constant-pressure surfaces.

APPENDIX

SIRS VERSUS MEAN RADIOSONDE

The first step in comparing the accuracy of SIRS with the accuracy of the radiosonde is to find an average discrepancy between them where data from both sources occur in close proximity. A search is made around the location of each SIRS sounding, and if at least three radiosondes with a reported wind and height are located within 1.5 gridlengths (1 gridlength = 381 km at 60°N), the SIRS sounding is considered eligible for verification. For each eligible SIRS report at each pressure level, the height value Z of each neighboring radiosonde is extrapolated to the SIRS location according to a geostrophic gradient obtained from the observed wind

$$ZE_i = Z_i - \frac{f}{g} [u_i dy_i - v_i dx_i]. \quad (1)$$

Z_i is the height and u_i and v_i are the components of the wind reported by the i th radiosonde; f is the Coriolis parameter and g is the acceleration of gravity; dx_i and dy_i are distance increments (in the wind component directions) separating the radiosonde from the SIRS.

A gross quality check is performed on the radiosondes by comparing each extrapolated height with the mean extrapolated height;

$$D_i = |ZE_i - \sum_{i=1}^N ZE_i / N| \quad (2)$$

where N (≥ 3) is the number of neighboring radiosondes. The radiosonde with the largest value of D is rejected if

the value is greater than a specified amount (e.g., 60 m at 500 mb). If less than three radiosondes remain after a rejection, the SIRS sounding is dropped from consideration; otherwise, the quality check is repeated without the rejected radiosonde.

Upon completion of the quality check, the mean extrapolated radiosonde value (\overline{ZE}) is subtracted from the SIRS value (S) to give the SIRS discrepancy (SE):

$$\overline{ZE}_j = \sum_{i=1}^N ZE_i / N \quad (3)$$

and

$$SE_j = S_j - \overline{ZE}_j \quad (4)$$

where j refers to the j th SIRS retrieval. Finally, for each pressure level the rms discrepancy is computed for all P eligible SIRS retrievals within a given cloud classification l :

$$\text{SIRS}_l = \left(\sum_{j=1}^P SE_j^2 / P \right)^{1/2} \quad (5)$$

A statistic similar to that of eq (5) is computed for the thickness between mandatory pressure levels by using the thickness implied by the SIRS heights and the mean extrapolated thickness implied by the radiosonde heights and thermal winds.

RADIOSONDE VERSUS MEAN RADIOSONDE

The statistic expressed by eq (5) does not give a true estimate of the absolute accuracy of the SIRS retrievals because both the radiosonde reports and the method of extrapolation contain error. However, it is possible to compare the accuracy of SIRS with the accuracy of the radiosonde by treating a sample of radiosondes as if they were SIRS and comparing the resultant statistics with those obtained from the true SIRS sample. This was done by choosing as pseudo-SIRS the radiosonde closest to each SIRS report used in computing eq (5). These pseudo-SIRS reports were processed exactly as the real SIRS reports were in eq (1) through (5) to give a rms discrepancy RAOB analogous to SIRS. The cloud category was assigned according to the cloud sensed by the real SIRS neighboring the pseudo-SIRS. The accuracy of SIRS heights relative to radiosonde heights is given by comparing SIRS with RAOB. A similar comparison is made for the thicknesses. Discrepancies in these comparisons are to a large extent independent of the analysis technique's error, which is common to both samples, although the samples are not exactly similar because some of the radiosondes used for comparison with the real SIRS have been used to establish pseudo-SIRS. This last point is discussed further below.

ACCURACY OF MEAN EXTRAPOLATED RADIOSONDE

A gross estimate of the accuracy of the extrapolation technique ANALYSIS is obtained by computing the

mean variance of the extrapolated radiosonde height values at each location.

$$V_j = \sum_{i=1}^N (ZE_i - \overline{ZE}_j)^2 / N; \quad (6)$$

this is used to compute the root mean of the individual variances at all locations within a given cloud classification

$$\text{ANALYSIS}_l = \left(\sum_{j=1}^P V_j / P \right)^{1/2} \quad (7)$$

The ANALYSIS value serves two purposes. First, because it is an approximation to the noise associated with the verification scheme, the discrepancy between ANALYSIS and SIRS (or RAOB) is an approximation to the real error in SIRS (or RAOB) data. In particular, suppose that eq (4) were rewritten

$$SE_j = S_j - (Z_j + E_j) \quad (8)$$

where Z_j is the true height and E_j is the error associated with approximating the true height from surrounding radiosondes. Then analogous to eq (5):

$$\begin{aligned} \text{SIRS}_l^2 = & \sum_{j=1}^P (S_j - Z_j)^2 / P + \sum_{j=1}^P E_j^2 / P \\ & + 2 \sum_{j=1}^P Z_j \times E_j / P - 2 \sum_{j=1}^P S_j \times E_j / P. \end{aligned} \quad (9)$$

If SIRS data are uncorrelated with the error and the latter is uncorrelated with the true height, the last two terms in eq (9) are zero and the mean square of the SIRS discrepancy is composed of the mean squares of (1) the real error in the SIRS data and (2) the error associated with approximating the true height. The difficulty with applying this definition rigorously in the present context is that the error associated with approximating the true height is only grossly represented by the ANALYSIS statistic, and there is no guarantee that the last two terms of eq (9) are zero. For these reasons, no attempt has been made to quantify the absolute error of SIRS data.

The second purpose served by the ANALYSIS statistic is investigation of the effect of including the pseudo-SIRS observations in the computation of the SIRS statistics. The ANALYSIS statistic was included in the computation of both SIRS and RAOB statistics and varied only slightly, rarely more than a meter. This is interpreted to mean that the inclusion of the pseudo-SIRS in the computation of the SIRS statistic did not contribute a bias.

REFERENCE

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